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Technical Note

ORIENTATION EFFECTS IN THE DEFORMATION OF MOLYBDENUM CRYSTALS

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Although much effort has been devoted to the problem, the nature of plastic flow in b.c.c metals is still not fully understood. Some of the difficulties encountered stem from the scarcity of information on orientation effects and the uncertainty as to the glide system in these metals. In an attempt to provide some of this information, the present investigation was carried out, using zone-refined molybdenum single crystals deformed in tension and in direct shear.

Considerable evidence exists to indicate that the primary slip system for molybdenum is $\{110\}\langle 111\rangle$ [(1)(2)]. Figs. 1 and 2 indicate that this is indeed the case for direct shear at room temperature (see ref.(3) for a description of the shear-testing equipment and procedure). Moreover, from Fig. 2, the shear stress on the $(\bar{1}23)$ is lower than on the (112). This would be the case if, as has been suggested [(4)(5)], slip on these two planes is in reality composite slip on non-parallel $\{110\}$-planes However, resolution of the stresses for both the orientations on the $(110)[1\bar{1}1]$ would lead to substantially smaller differences in shear stresses between the orientations than was observed here.

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Rose et al[6] showed that the orientation of the tensile axis of single crystals of tungsten had a marked influence on their stress-strain behavior. The tensile curves obtained with molybdenum crystals from which the curves of Fig. 3 were derived look similar to those obtained for tungsten.

A comparison of the (110)[1$\bar{1}$1] curve in Fig. 2 with the tensile curve for the [110] orientation in Fig. 3 corroborates the assumption that slip occurs on the (110)[1$\bar{1}$1] system having the greatest resolved shear stress. The [110] and [100] tensile orientation have the same stress-resolution factor, yet, the appearance of the corresponding curves in Fig. 3 differs greatly. This is an indication that the assumption of simple slip on the (110)[1$\bar{1}$1] does not apply to the [100] tensile orientation.

The activation volume, v*, was determined by the differential strain-rate method from the equation

$$v^* = kT \frac{\partial \ln\dot{\gamma}}{\partial \tau_a} \cong kT \frac{\ln\dot{\gamma}_1 - \ln\dot{\gamma}_2}{\tau_{a_1} - \tau_{a_2}}$$

that is, by the observation of the change in applied stresses, τ_a, as a result of a sudden change in strain rate, $\dot{\gamma}$, at constant temperature, T, and constant shear strain, γ. The activation volume was found to decrease with strain at all temperatures, orientations, and strain rates investigated. A typical set of curves is given in Fig. 4. The difference in activation volume between the different orientations is greatest for small strains and vanishes upon large deformations. It was also characteristic for these tests that the activation volume for all different orientations decreased with increased applied stress.

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It appears from these findings that the plastic deformation mechanisms in molybdenum are orientation dependent and involve interactions affected by the stress state.

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FIGURE CAPTIONS

Fig. 1. Stress vs. strain for molybdenum crystals tested in direct shear on the (110) plane along different directions. The lines in the circles indicate the orientations of the <111>.

Fig. 2. Stress vs. strain for molybdenum crystals tested in direct shear along the [111] direction on different planes. The lines in the circles indicate the orientations of the <111>.

Fig. 3. Shear stress vs. shear strain for molybdenum crystals tested in tension for different orientations of the tensile axis. Tensile stresses and strain were converted assuming single glide on the most favorably oriented {110}<111>.

Fig. 4. Activation volume vs. strain for molybdenum crystals tested in direct shear along the <111> on different planes. Data were obtained by differential strain-rate method and computed on the basis of shear stress resolved on the (110). The lines in the circles indicate the orientations of the <111>.

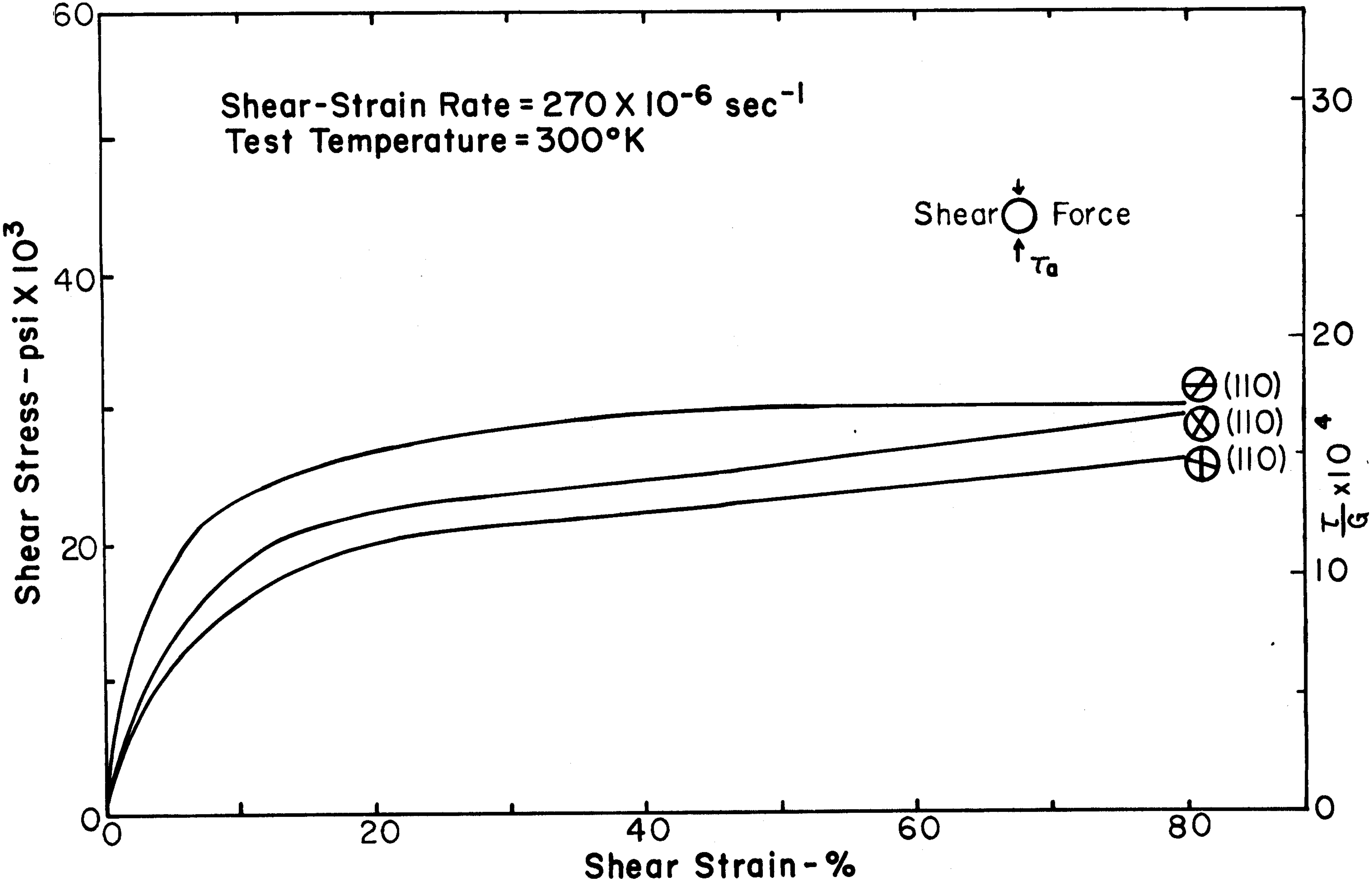
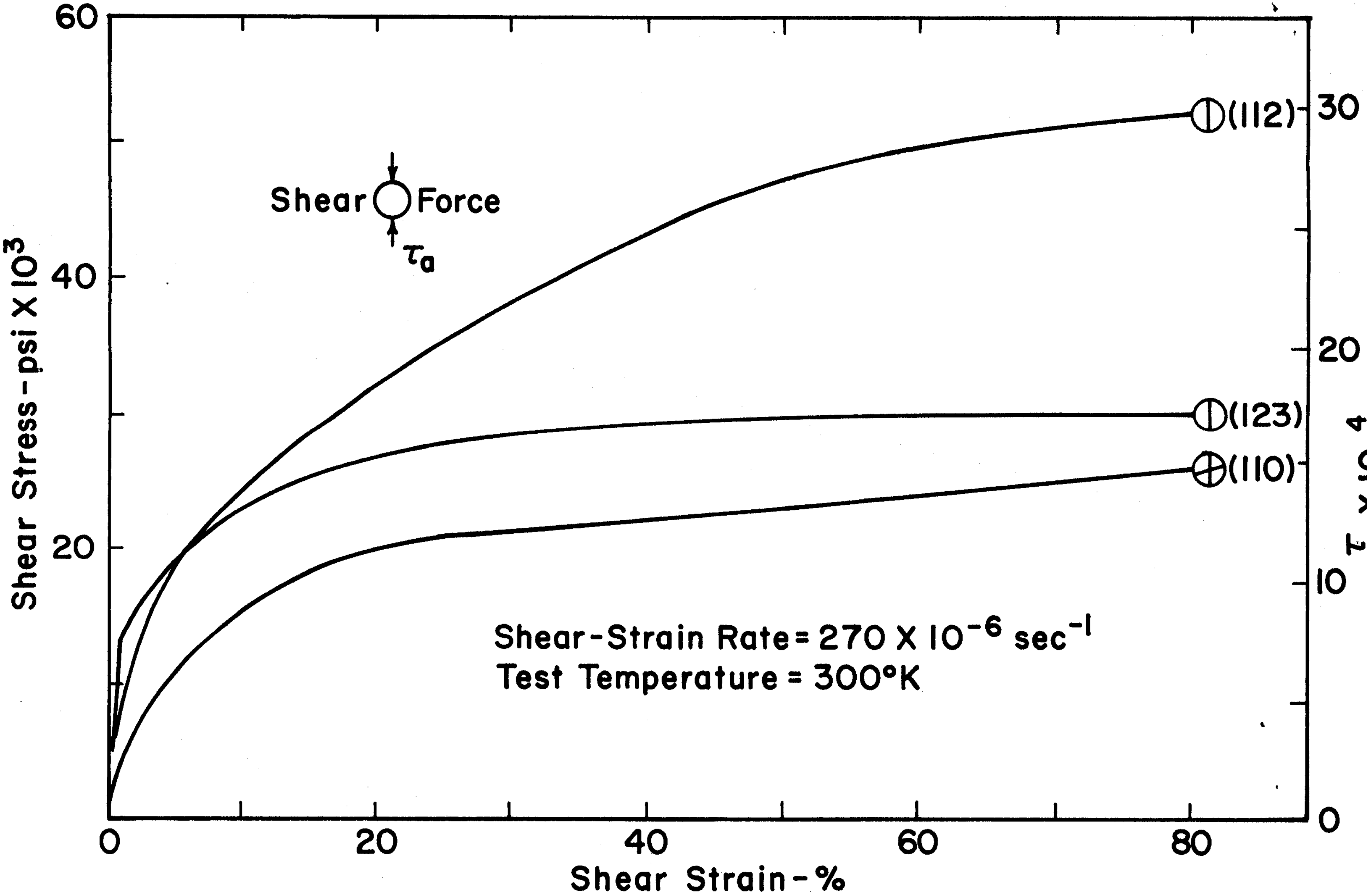

Shear-Strain Rate = 270 X 10^-6 sec^-1
Test Temperature = 300°K
Shear Force
τa
(110)
(110)
(110)
Shear Stress - psi X 10^3
Shear Strain - %
τ/G x 10^4
60
40
20
0
0
20
40
60
80
30
20
10
0

Fig. 1



60
40
20
0
20
40
60
80
30
20
10
0
Shear Stress - psi X 10³
Shear Strain - %
$\frac{\tau}{G}$ X 10⁴
(112)
(123)
(110)
Shear
Force
τ_a
Shear-Strain Rate = 270 X 10⁻⁶ sec⁻¹
Test Temperature = 300°K

Fig. 2

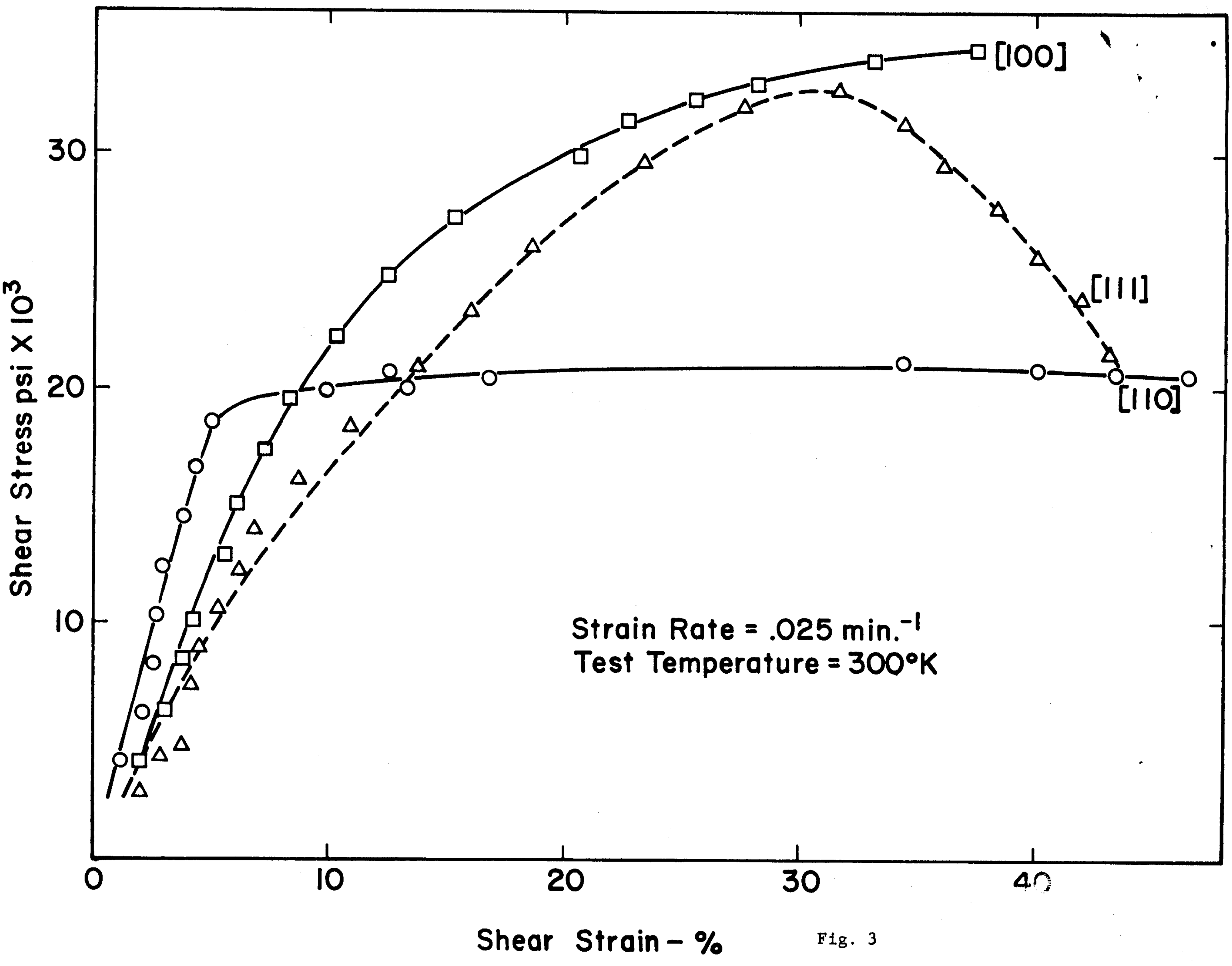
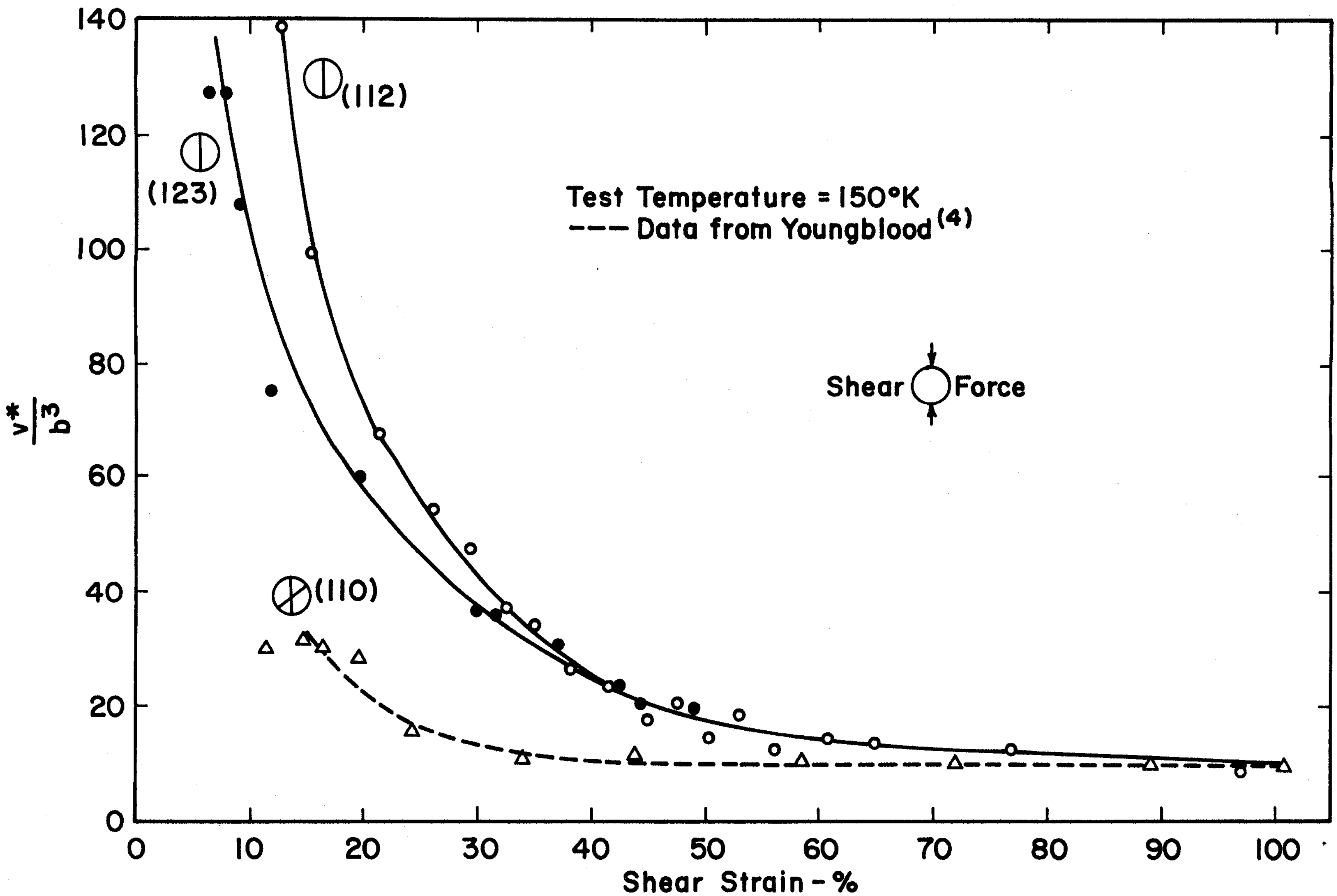

[100]
[111]
[110]
30
20
10
0
10
20
30
40
Strain Rate = .025 min.$^{-1}$
Test Temperature = 300°K
Shear Stress psi X 10^3
Shear Strain – %

Fig. 3



140
120
100
80
60
40
20
0
10
30
50
70
90
$\frac{v^*}{b^3}$
(112)
(123)
(110)
Test Temperature = 150°K
--- Data from Youngblood (4)
Shear
Force
Shear Strain - %

Fig. 4